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MICROWAVE TUBE RELIABILITY

1 June 1976

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Prepared for
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Data obtained from tube manufacturers, system manufacturers, and users point to problems resulting from low-volume production, technological gaps, lack of failure data feedback to the manufacturer, limited development funding, inadequate reliability assurance, and the lack of a comprehensive program of repair and recycle. Past efforts to improve reliability are surveyed. Government-industry interaction is discussed, and it is suggested that it might be appropriate to encourage the continued survival of the remaining manufacturers of microwave tubes. Specific development programs are recommended in support of high-power tubes in the areas of airborne systems, shipboard systems, and support technology.		

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OBJECTIVE

Establish a data base describing the present level of reliability of microwave tubes and recommend solutions to reliability problems. Obtain data from tube manufacturers, system manufacturers, and users.

RESULTS

As a result of visits to manufacturers and users, review of data, and meetings of the three services, the following conclusions are drawn:

LOW-VOLUME PRODUCTION

1. The tube industry needs to be made more efficient through standardization so as to reduce the vast number of tube types.
2. Low production volume makes it uneconomical for the manufacturer to invest in improving his product or his production methods.

TECHNOLOGICAL GAPS

1. Government programs are lacking in some low-glamor areas of materials and high-power component R&D. Very little effort is directed toward improving dielectrics, capacitors, etc. The economics is such that the commercial market is not oriented to the needs of the military high-power component. For improved tube and transmitter reliability, the government should invest in component development (and in this way minimize the current practices of screening or burning-in, which raise component cost).

FAILURE DATA FEEDBACK

1. The component manufacturer at present does not get enough feedback on failure modes and failure mechanisms.

ECONOMY OF TUBE DEVELOPMENT

1. Tube development programs usually do not have sufficient funds to (a) establish feasibility of design; and (b) carry out advanced development and testing for reliability.
2. Tubes that have been developed and have matured are not evaluated for design margins. Relationships between peak power, average power, operating temperature, and VSWR need to be established for generic tube types as well as for specific tubes in order to provide system designers tubes of proved performance.

PRESENT-DAY PRACTICE OF RELIABILITY ASSURANCE

1. The systems manufacturer has the responsibility of assuring field reliability and, in the case of tubes, he does this through testing and screening of the tubes before they go into systems. This is most often accomplished by system checkout and/or burn-in. This is often costly and does not address the long-range reliability problems.
2. Tubes for new systems are usually not integrated into the system early enough in the program so as to identify tube-system incompatibilities at a point in the development cycle at which they can economically be corrected.

TUBE RECYCLING

1. Tube repair and recycling can substantially reduce costs. A comprehensive program in this area is lacking. A more universal application should be achieved.

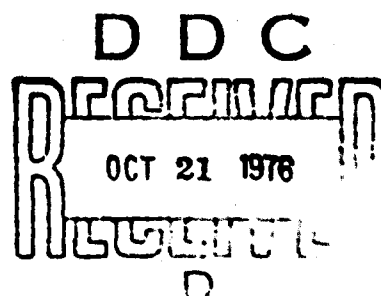
RECOMMENDATIONS

A list of specific recommended programs is given in the report proper (Recommended Technological Development Programs in Support of High-power Tubes). Programs in airborne systems, shipboard systems, and support technology for high-power tubes are included.

ADMINISTRATIVE INFORMATION

This study was carried out under 62762N, F54545 (NELC R207), by the Surveillance and Countermeasures Division from July 1974 to December 1975 and was sponsored by NAVELEX Code 304. The report was originally approved for publication 30 December 1975 with distribution limited to US Government agencies only without prior release approval by NELC.

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BACKGROUND

The DoD problems which motivated this tube reliability study are relatively clear and evident; however, identifying the underlying causes and possible solutions is more difficult. A 1-year study was undertaken to address just that problem.

During the course of the study, certain weaknesses in the tube life cycle became evident. These can be divided into two basic areas — the institutional problems and technological problem areas.

Institutional weaknesses relate to the way the Navy buys electronic countermeasure (ECM) and radar systems. In the usual development cycle, the system developer is the prime contractor, and the tube vendor is generally a subcontractor answerable to the system house only. (This situation became obvious during the collecting of tube failure data when, at several companies, legal people were brought in and contract clauses were offered in place of tube failure data.) Tube reliability is usually handled by the system house, who will achieve a tolerable degree of reliability by screening. This does not really solve the tube design and manufacturing problems and is ultimately more costly.

Another institutional failing is the lack of a comprehensive tube recycling program. In recent years, tube repair has been increasingly applied, but it is still applied only to a limited extent. One contractor reported that they have had an open-ended repair contract for 3 years, but have still to receive the first tube. There are two profit areas in tube recycling. One is the cost and material savings. In one specific case, tubes leave the repair contractor's plant with full new-tube warranty at a cost of 60% or less of new-tube replacement. Repair tube yield is about 70% and some tubes are recycled several times. The second area of gain is the potential offered through repair efforts by identifying generic weaknesses in tube design. This has been demonstrated in one case of increasing tube life by a factor of two. Failure-mode statistics generated as a by-product of repair programs also provide significant data for application to tubes in development. This last factor requires that those involved in tube development and manufacturing (both DoD laboratories and contractors) be in the repair loop.

Military tube production is almost always "low volume," so that industry does not have the economic motivation to make the necessary investment in low-cost production tooling and techniques. There are two factors to the solution of this problem: one is for DoD to reduce the large number of tube types (standardization) and the second is for DoD to finance manufacturing technology development.

This report gives the failure data in summary form and recommended R&D efforts to fill gaps in the technology. These represent specific material and technology problems that were brought up again and again by tube developers.

Some comments on the data obtained and the conclusions drawn are now given. Much of the failure data available do not constitute a scientific sampling useful for statistical analysis and valid conclusions. Often the numbers are too small to be statistically significant, or the data were not made available to the authors (for reasons already discussed). Therefore, the conclusions represent the engineering judgments of the authors made after evaluating the available data, including the experience of developers, users, and maintenance people. Also included in the data base were previous efforts on reliability studies as described in referenced reports.

In addition to the above sources of data, a tri-service working group on reliability was convened by NAVELEX. Three meetings were held and the results are reflected in this report.

INTRODUCTION AND CONCLUSIONS

The objectives of this study were to establish a data base describing the present level of reliability of microwave tubes, to discuss cost considerations, and, if appropriate, recommend solutions to reliability problems. The approach was to obtain data from tube manufacturers, system manufacturers, and users. Acquiring data began with the tube manufacturers.

Much of the tube performance information was obtained through personal contacts with people in tube development and operations. For the most part, the data provided describe in-house rather than in-field failures. The general feeling by industry is that field data are not sufficiently available to them, creating a gap in their information on failure modes and failure statistics. For this report, some experience data were obtained through interviews with operator personnel.

As a result of the visits, review of data, and meetings of the three services, the following conclusions are drawn.

LOW-VOLUME PRODUCTION

The tube industry needs to be made more efficient through standardization so as to reduce the vast number of tube types.

Low production volume makes it uneconomical for the manufacturer to invest in improving his product or his production methods.

TECHNOLOGICAL GAPS

Government programs are lacking in some specific areas of materials and high-power component R&D for both the tube and associated devices. Very little effort is directed toward improving dielectrics, capacitors, etc. The economics is such that the commercial market is not oriented to the needs of the military high-power component. For improved tube and transmitter reliability, the government should invest in component development (and in this way minimize the current practices of screening or burning-in, which raise component cost).

FAILURE DATA FEEDBACK

The component manufacturer at present does not get enough feedback on failure modes and failure mechanisms.

ECONOMY OF TUBE DEVELOPMENT

Tube development programs usually do not have sufficient funds to: (1) establish feasibility of design; and (2) carry out advanced development and testing for reliability.

Tubes that have been developed and matured are not evaluated for design margins. Relationships between peak power, average power, operating temperature, and VSWR need to be established for generic tube types as well as for specific tubes in order to provide system designers with tubes of proved performance.

PRESENT-DAY PRACTICE OF RELIABILITY ASSURANCE

The systems manufacturer has the responsibility of assuring field reliability and, in the case of tubes, he does this through testing and screening of the tubes before they go into systems. This is most often accomplished by system checkout and/or burn-in. This is often costly and does not address the long-range reliability problems.

Tubes for new systems are not usually integrated into the system early in the program so as to identify tube-system incompatibilities.

TUBE RECYCLING

Tube repair and recycling can substantially reduce costs. A comprehensive program in this area is lacking.

SYSTEM AND TUBE RELIABILITY

SYSTEM DEVELOPMENT IMPACT ON TUBE RELIABILITY

System houses involuntarily contribute to the low reliability attributed to tubes. Ideally, tubes should have a conservative design and be derated for the application. The power supply for the tube should have good regulation and contain adequate protection circuitry. New systems push the state of the art — then demand increased power, reduced tube size, reduced tube weight, and higher thermal densities. These needs derived from the system performance requirements are forced on the system house, are passed on to the tube vendor, and often result in tube problems.

There are many instances of system requirements pushing tube performance. For example, when the system line losses are 2 dB more than projected, the tube is required to provide an additional 2 dB of power to offset the loss. The tube must provide additional power to offset filter losses. In addition, the tube may be required to accept the reflected harmonic power. Under present conditions, tube reliability is incompatible with performance goals.

Tubes would be more reliable if they were allowed to mature. Often sufficient funds are not invested to develop tubes in advance of system development.

Some specific examples of tube failures are cited to illustrate common tube-system problems. Microwave Associates provided data on tubes used in the EA6B ECM system. The tubes discussed demonstrate a 2000-hour life in the laboratory but exhibit only a 200-hour life in systems.

The tubes reported on were broadband, helix tubes for three frequencies of the AN/ALQ-99. Some of the tubes were PPM focused and some solenoid focused. Forty percent of the tubes returned were found when tested to be within specifications. Failure modes of the remaining tubes were

- Open heater
- Low power
- Anode-to-ground shorts
- Mutilated cables
- Dropped tubes

The cause of the heater problem was related to two probable factors – transients from the power supply and internal arcing. (Zener diodes placed back-to-back across the heater were suggested as the solution.)

Other problem areas were identified for these tubes. The cathode loading varies from 0.5 to 2 A/cm². For maximum reliability it may be desirable for the tube to operate with a loading density less than 0.5 A/cm².

The band 4 tube was described as being too small. For the frequency and power levels required, the tube should be made considerably larger.

Focusing was identified as a critical area. Any perturbation of the magnetic field causes the beam to expand which then causes tube failure.

The rf loading on the tubes creates problems. Some tubes operated with low-pass filters became gassy. Other tubes operated into high-pass filters demonstrated a tendency to oscillate. The use of band-pass filters, however, allowed satisfactory operation.

Electromagnetic interference (emi) is a problem in high-gain systems. Rf leakage from rotary joints or from the collector leads couples back to low-level stages or to power leads and induces transients on the power lines. These transients are similar to control signals and so can activate transmitter fault logic circuitry and cause good tubes to be removed from the system. Also, this leakage coupled back to a low-level stage on the input could create instabilities and thereby also cause tube removals.

These examples show that part of the solution to improved tube reliability rests with improvement in the system design areas and not the tube.

Another system-generated tube problem surfaced in the AN/ALQ-99. Ninety percent of the time, the tube is in standby condition with the heater on and the solenoid off. Under these conditions, the emitter runs hotter because it lacks the cooling provided by electron emission. For this application, the reliability performance might be improved by reducing the heater voltages during standby. The heater voltage should drop from 12.8 to 10.4 V (below the knee of the curve).

FIELD RELIABILITY VERSUS LABORATORY RELIABILITY

RADC in a report (ref 1) has shown the necessity of obtaining field data for identifying reliability problem areas. In this report, RADC states that the field reliability is lower than that demonstrated in the laboratories by a ratio as high as 5:1. The report states that almost 50% of field failures are environmentally related. Temperature, vibration, on-off cycling, input voltage regulation, humidity, and altitude are the primary environmental factors that affect reliability. Temperature effects cause 40%, vibration causes 27%, moisture causes 19%, and altitude causes 2% of the failures.

A common failing is that the operating history for avionic systems is difficult to obtain. Flight hours are readily available but differ from equipment operating hours by such factors as duty cycle, ground operating time while installed in aircraft, and bench time. Equipment operating time can be considerably longer than flight time.

Outside pressures of delivery schedules and budgets can cause the system field reliability to be less than optimum. Equipment is often delivered before reliability evaluation is complete. Problems detected during the evaluation will not be incorporated into early production runs. Therefore, until some later point in time, the reliability of the field hardware may be lower than the demonstrated value.

1. Rome Air Development Center Report RADC-TR-74-266, "Evaluation of Environmental Profiles for Reliability Demonstration."

DATA AND FAILURE MECHANISMS

DATA REQUIRED FOR RELIABILITY EVALUATION

There are basically three levels of failure data involved. The first level is that which indicates the existence of a system or subsystem problem. These data contain operating time in a socket (or indicate that there has possibly been an increase in the tube usage). The information indicates only that an undesirable situation exists, not necessarily a tube problem. The second level of data describes the failure symptoms; eg. low power, open filament, or a broken window. These data still are not indicative of a tube problem necessarily, but suggest that there is a system problem which is generating tube failures. The symptoms may reflect tube weaknesses or they may reflect system component deterioration, improper maintenance, or improper mode of operation. The third level of data is derived from a detailed examination of the tube externally and internally. Here, the failure mechanism is identified, and also the presence of other symptoms is established. At this level, tube weaknesses can be identified and corrected. An example of this type of fault occurred with the high-band tube of the AN/ALQ-126. A number of rf output windows cracked. Detailed study of the symptoms and the window structure showed that, under thermal cycling, excessive expansion of a teflon ring was causing the ceramic to crack. This third level of data is essential for identifying the nature of the failure and the available solutions.

Data obtained from the system manufacturer's observed symptoms (second level data) can be misleading, as can be seen from the following example. A series of data printouts was obtained from Varian. On one of these printouts, the faults observed by the systems manufacturer were listed and on another printout were listed the faults identified by Varian. The following examples are indicative of the difference between a system failure report (second-level data) and the tube manufacturer's (third-level data).

COMPARISON BETWEEN FAILURE REPORTS AND FAILURE ANALYSIS BY THE TUBE MANUFACTURER

Group	Symptom Described by Field or System Failure Data	Tube Manufacturer's Analysis
A	Open heater/filament	Solder defect Improper assembly
B	Failed hi-pot	Solder defect Potting defect Lead damage Incorrect assembly No data reported Interelectrode leakage
C	No output (3) Low power, hole in band (16) High beam voltage (1) Trips circuit breaker (1) Connector pin broken loose (2)	Improper pulse shape applied to the tube

No customer complaint (2)
Open helix (1)
High harmonics, low power (1)

The group A and B symptoms indicated by the failure report data were identified by the tube manufacturer as defects shown in the right-hand column.

The group C symptoms were all identified by the tube manufacturer as being caused by a single cause. The number in parentheses represents the number of incidents reported.

INFANT-TUBE FAULTS AND PROBABLE POINTS FOR OBSERVATION

Tubes in the early stages of life show a high failure rate. Some failure modes are tabulated below:

<u>Failure Mode</u>	<u>Comments</u>
Vacuum leak	Usually does not occur in new tubes. When present, cause is usually human error. Some tubes are over-brazed. If the braze ring is too large, the braze may be weakened.
Open or shorted heater	Uncommon
Cathode poisoning	Uncommon
Internal shorts or collector breakdown	Dimensional error; or physical projection overlooked or caused during final seal-in.
Electrical breakdown	Occurs outside the envelope.
Potting failure	Gun and collector assembly susceptible to this type failure. Potting material fails to adhere properly and results in arcing.
High-temperature failures	Tubes are improperly placed on the heat sink.
Arcing	Tube arcs and takes out the grid modulator.

Another set of fault factors dominates when the tube is integrated into the system:

<u>Fault Factor</u>	<u>Comments</u>
Thermal environment	Thermal density causes components to overheat.
Improper voltages	
Improper turn-on	
Improper turn-off	Helix voltage drops into the stop band, allowing beam to blow up. Collector drops too fast, causing electrons to return to the interaction region.

The aforementioned are typical of the kinds of faults observed at the tube manufacturer's plant or during system acceptance testing of tubes.

There is yet another set of failures that relate to tube environment and occur during environmental testing or installation into the system:

Tube failure during shock and/or vibration.

Window failures caused by temperature, VSWR, or both.

Rf circuit failures (thermal).

High helix current in the overdrive condition.

Failure of output circuit (severing of circuit).

Open input helix caused by very high current or low helix voltage. Tube may be within stop band.

The presence of these failure modes for a particular tube design can be and is identified by the tube or system house during the early stages of tube or system life. Analysis of data on the AN/ALQ-126 shows this.

Formal or informal burn-in consisting of 25 to 100 or more hours of tube-system operation under normal and thermally cycled conditions screens out these problems. The problems that remain are not tube-system problems, but a new set generated while the system is operational. These problems represent long-term failure or failure modes sensitive to abnormal operational stress.

Another infant-tube set of problems was reported by The United Aircraft Corporation, Norden Division, as a heater problem (under contract N00019-72-C-0548). The report stated that stray or noncanceled magnetic fields flowing through the filament tend to defocus the field. They also indicated that variations of cathode temperature affect the energy distribution of the electrons leaving the cathode or density of electron beam and thus change the beam focus.

TRANSIENT PROBLEMS

Many power tubes operate in a pulsed mode. Either the entire tube is pulsed on or off or the tube is pulsed on by a grid pulse. The transient phenomena associated with the pulsing of the tube are not fully understood. Some of the problems that occur may be associated with the rapid change of cathode current within the tube.

The nature of the transient effects whether random or derived from a pulser is not well understood. Studies are lacking which would identify and develop pulser designs that optimize the transfer of the pulse from the modulating source to the device to be modulated. The pulser design should be such that tubes used with the modulator are insensitive to the design.

Currently, one tube is used in an airborne system that will not operate properly with the present system modulator. In order to provide for proper performance, a transfer network is being developed for use with the tube. This network provides a fix for one specific system problem, but it does not help in avoiding future problems.

Transients, whether from arcing or other sources, affect the performance of the tube protection circuits. A pulsed tube reflects energy back along the power supply lines, causing spurious signals. The coupling of these signals to various control voltage lines can trigger false failure indications or can deactivate protection circuitry. Transient phenomena, pulsed phenomena, and pulser characteristics need to be studied in order to reduce the impact of transients and pulsing on tube-system performance.

HUMAN FACTORS AFFECTING TUBE RELIABILITY

Human factors must be addressed in order to realize maximum improvement of reliability. Humans as operators, installers, and maintainers are the decision-makers in all matters which impact on the ultimate reliability of the systems. The contribution may be 20 to 30%.

Many of the reported failed tubes returned to the tube manufacturer are good tubes. Improved techniques could assist the technicians in the determination of the condition of a tube.

Tube and transmitters need to be designed so that no (or a minimum of) adjustments are required during tube installation. Incorrect settings of voltages, filament voltage in particular, shorten tube life. Tube mishandling causes between 10 and 30% of all failures. These failures can be dropped tubes or tubes that have been distorted by improper lifting. Tubes with attached leads are often damaged by improper handling of the leads.

From some of the experience data gathered, it appears that the motivation of the electronic technician (as much as his training) is a critical component in tube reliability.

A field engineer stated that the current Navy technician does not get the training skills of his counterpart of 5 years ago. The engineer stated that a new crew is assigned to a ship after each trip. He indicated that the first 3 months of each trip is a training period for the technician.

ADDITIONAL TUBE RELIABILITY FACTORS

QUALITY CONTROL IN TUBE MANUFACTURING

Review of failure data for tubes shows product and process control is insufficient. During the tube fabrication process actions occur which the manufacturer is unable to control to assure tube quality and which lead to early-life failures. Some of these effects can be checked and corrected when the tube is completed and some require burn-in.

The following is a list of some failures that relate to fabrication:

- Filament failures at poor weld junctions.

- Structural defects occurring because of poor brazes.

- Leaks occurring because O-ring materials are not compatible with coolant fluids.

- Cracked ceramics because of thermal expansion.

Arcing problems caused by air voids within the encapsulated structure. This type problem can be identified by applying high voltage and noting the presence of arcing or leakage current. Usually an instrument called a hi-pot tester is used to identify this problem.

Process control in tube manufacturing should be established early in the development cycle of a tube. A major push towards improved reliability can be obtained through better controls of the materials and techniques used in tube assembly. Correction of these weaknesses will take an investment that the manufacturer is not in a position to make, again due to low-volume production.

MATERIALS AND COMPONENT CONTRIBUTION TO TUBE RELIABILITY

Tube manufacturers indicated that many failure problems stem not from the tube design but from components and materials purchased from outside vendors. In the area of connectors, for example, coaxial connectors are at the joints and result in broken windows. Dc connectors do not always perform properly at high altitudes. Fit tolerances are not carefully controlled. Output connectors are not required to be placed at natural connector points. Failures of these connectors have caused tube failures. In the area of materials from outside sources, Coolanol 35 has been identified as clogging coolant channels. Under high-temperature conditions, the synthetic oil decomposes and the residue clogs the passageway. The result is overheating and failed tubes. Potting materials must bond to metal, withstand low temperatures, and be stable at high temperatures. In addition, the material should have a temperature expansion coefficient such that temperature cycling does not create voids. The potting compounds also need improving so as to improve bonding to materials such as teflon.

Microwave Associates reports that in the first 35 production tubes for band 5/6 of the ALQ-99, 11 tubes were returned because of potting problems, dc connector/rf connector misfit, or mechanical weakness.

Rf feedback from the isolated collector leads is a problem. Specific techniques are needed to strip the rf off the dc lines. This feedback interferes with protect circuitry and with tube performance. A good lossy cable or some other technique is required to prevent this feedback.

Raytheon also identified potting as a problem. Raytheon noted that during the past 4 years the reliability of standard parts — HV pulse transformers, power resistors, and others — has decreased (ref 2). Potting was identified as a cause of a high-voltage transformer problem. They further stated that changes are needed in encapsulation material and in potting processes. They believe that the search for lower cost and the pressure of shorter schedules have produced a lowering of item quality.

Reactive harmonic filters are another cause of tube failure. Many harmonic filters are reactive and return the second-harmonic power back to the tube. Most tubes cannot withstand this reflected power, and failure results.

High-power, ridged waveguide components need to be developed for high-band application. Many tube houses are dissatisfied with the coaxial components which are presently used.

Component, connector, and material problems, such as the ones discussed above, can mask the inherent reliability of traveling wave tubes. In order to achieve higher tube reliability, these areas should be addressed together with the tube design but specific programs are not being proposed in this paper.

POWER SUPPLIES

The design and construction quality of power supplies are critical to the improvement of tube reliability. The energy required to destroy a tube is derived from the power supply, and if the tube and power supply are not properly mated, failures occur. One of two sources can carry out the power supply development — the tube manufacturer or the system manufacturer.

2. Paper presented at 1974 Annual Reliability and Maintainability Program, "Reliability Growth — Actual versus Predicted," Raytheon, Inc.

Requirements for a good supply extend beyond voltage and current. ECM supplies must have high efficiency and operate under high thermal conditions. They must be able to handle high current surges because of the low input voltages. The rise and fall rates of the voltages must be controlled to avoid beam blow-up. The power supply energy needs to be controlled so that during an arc neither the tube nor the supply is damaged. Load lines for the grid voltage must be designed so as to avoid failure conditions. Last of all, good regulation is critical to achieving reliable TWT performance.

The ECM system house recognizes these requirements but is further constrained by weight and size requirements. The pressure on the ECM system developer is to get the system out; reliability is secondary.

Power supply problems were identified as follows:

1. The power supply manufacturer is the last one to get a specification and must be the first to deliver. This sequence does not allow adequate time to mate the tubes and power supply, particularly if the tube design is not fixed.
2. Components (high voltage and high power) are not designed to meet military environmental requirements. The available components are those items designed for the TV/auto industry: they represent good economy but do vary from batch to batch. R&D programs are needed to identify specific problems and, using modern technology, develop improved components.
3. High-voltage encapsulation is a problem. Potting materials capable of operating at 300°C are needed. The commercial supplier of these materials does not see a large enough market for an improved product to justify his investing in developing materials with the special characteristics needed by the power supply developer.
4. A reliability data bank for supplies and modulators needs to be developed. The data should relate reliability to size, weight, and power.
5. The power supply developers for airborne ECM systems would like the available prime power to be at a frequency higher than 400 Hz. It would be desirable to obtain the power at a frequency as high as 3000 Hz. The higher frequencies would allow improved reliability with low weight and volume.

Also identified is the unavailability of reliable parts designed for military applications. The present solution to the problem of obtaining component reliability is to first screen the components during incoming inspection and then to apply burn-in at the sub-assembly (power supply) and system levels. Both Sanders and ITT use this approach to achieve reliability goals. This technique affords a short-term solution and is ultimately expensive.

The tube-power supply interface represents a critical area of reliability. The tube must be tested with the system power supply in the operational environment. The tube manufacturer builds a tube that works well with the husky, general power supply used in the development laboratory. The system supply is limited by system power and weight and is temperature sensitive. In addition, transients are present in the system supply that differ from those occurring in the tube plant power supply. The differences between the two supplies cause part of the difference between tube life in the laboratory and tube life in the system.

The adequacy of the power supply in systems is also affected by economics. It has been stated that at times the system manufacturer is unable to pay the price for the kind of power supply needed for reliable tube performance.

The results of discussions with industry show that two things must be done as a part of a task to improve reliability.

Develop a line of reliable components for high-voltage, high-power applications.

Integrate the tube and power supply as early as possible in the system development cycle.

PROTECTION CIRCUITRY

Protection circuitry has been identified as being unsatisfactory. (Slow protect circuitry response was identified early in the AN/AWG-9 system program.)

Several components have been shown to be poor in quality, and programs are needed to improve both the quality and the performance of these devices:

Current sensing transformers are poor in quality. These need to be improved.

High-voltage relays are a problem. They are prone to leakage and coil failures. In addition, core potting problems exist. The relays should be evaluated and improvements made to give reliable high-voltage, high-temperature performance.

Solid-state circuitry has been identified as a problem. SCRs built into protect circuitry have been activated by transients, leading to false identification of problems. It has also been stated that, during some faults, the solid-state circuits do not respond properly, permitting tube and power supply failures to occur. Protection circuitry in general needs to be investigated and proper techniques need to be developed for the use of solid-state circuitry in a high-voltage or transient environment.

Crowbars need to be reevaluated for use in tube protection. These devices can be used to protect tubes but are not used because of space limitations or because of their tendency to generate transients. Smaller devices with transient control need to be developed.

New Sensors need to be explored. Optical, x-ray, and acoustic energy are sometimes associated with the early stages of tube failure, and the feasibility of economical monitoring devices needs to be established.

Emphasis needs to be placed on protection circuitry and sensors. Present methods monitor tube currents, voltages, temperature, and reverse power. New parameters and sensors for tube and power supply protection need to be identified and used for transmitter protection.

PAST EFFORTS TO IMPROVE RELIABILITY

SANDERS RELIABILITY EFFORTS

Sanders Associates provided good documentation regarding reliability problems associated with tube and system development of the AN/ALQ-126. The AN/ALQ-126 is a deception repeater ECM system internally mounted on the Navy's F4's. The system is based on experience with the AN/ALQ-94, the AN/ALQ-51, and the AN/ALQ-100.

The box for the AN/ALQ-126 is the same 2.3 cubic feet used for the AN/ALQ-51 in 1960. The AN/ALQ-51 system weighed 128 pounds, contained three tubes, and covered

one octave. For the AN/ALQ-100 in 1965, another octave was added to the same box. The AN/ALQ-126 produced in 1970 has yet another octave, using nine tubes, and in 1974 the duty cycle was increased. All these versions were enclosed within the same spatial confines.

The low-band tubes were used in the AN/ALQ-100. Internal parts of the tube are the same as those of the low-band tubes for the AN/ALQ-126 - only the external parts are different.

Evolution of the AN/ALQ-126 shows the basic problem of ECM. Performance requirements are constantly escalating; ie, more and more capability is put in the same box with a consequent increase in power density and operating ambient temperature.

At the system level, the PRIDE tube does not present an obvious reliability problem, since a high degree of screening takes place (which adversely impacts on tube cost and yield). On the next to last tube production buy, the leading manufacturer's cost of the high-band tube went from \$6K to \$11k on the last buy solution of the upper band edge gain problem cost was reduced to \$6775. At the high end of the band, many of the tubes exhibited low output power (0.5 to 1.0 dB low). Tube problems were attributed to poor beam optics and inadequate tolerance control in production. In addition, control of support rod attenuation was a problem. A second source yielded a high-band tube which was incompatible with the modulator. A transfer network was built into the tube to make it compatible. The reliability of the fix has yet to be determined.

The third tube for the socket remains to be proved. Initial efforts show that the tube can meet the rf performance requirements, but there are other problems yet to be solved.

The other power amplifier tubes used in this system are mature. They have been used in the AN/ALQ-100, which is the equivalent of the two lower bands in the AN/ALQ-126. The failures that have been observed with the low-band tubes have been fixed. Data from Sanders show that all faults have been resolved. Additional data from USS FORRESTAL show two low-band failures and six high-band failures for 81 systems during an 8-month period. No further effort is needed for the low-band tubes.

Sanders has documented the problems that it has encountered with each system and has used the data to improve each new system. In addition, the specific tube data have led to improved tubes for each new system. In spite of the long experience that Sanders and the tube industry have acquired in making and using the low-band tubes for the AN/ALQ-126, problems have occurred. Problems of insufficient quality control for items such as O-rings, connectors, and teflon inserts used with rf windows have occurred. These particular problems have been solved as a result of screening by Sanders, which is the usual system house approach to tube problems. It can be anticipated that other problems will occur because of lack of control of these auxiliary components.

The current problems with the AN/ALQ-126 are the result of the extreme environmental conditions that now exist in the box. The requirement for reliable tube operation with a base-plate temperature of 125°C has led to problems in integrating the tube with the system. The requirement for the tube to operate into a 4:1 VSWR has led to backward-wave oscillations, and the bandwidth has led to low-power problems at the band edge.

The conclusion drawn from the Sanders experience is that despite extensive designing and testing for improved reliability, some difficulties always show up when the tube is mated with the system for the first time. This is not to say that the effort is not needed, but rather that there seems to be an irreducible minimum amount of birth pains associated with new developments. Also, basic tube problems (especially those impacting on long-term reliability) are not properly addressed by the system house.

STANDARDIZATION EFFORTS

Standardization of tubes for ECM systems will increase tube production volumes so that tube costs will be lower and tube reliability increased. One example of a standardization effort is that for octave and multioctave microwave amplifiers. The Naval Electronics Engineering Office, Code 401E, Norfolk, is completing a task to provide universal solid-state amplifiers and low-band TWT amplifiers for EW systems. The program began in 1969 with the task of standardizing 7-10-GHz TWT amplifiers that would replace several different types which require large, complex, hard-to-adjust, low-reliability power supplies. The new type amplifier has an integral nonadjustment power supply with a minimum of 2000 hours' warranted life for use in both active and passive EW systems on surface and subsurface vessels.

After carefully reviewing the 7-12-GHz amplifier requirements in the various EW systems, a set of parameters was established which would satisfy the many system needs. A detailed procurement specification was then written and a contract awarded. Since then, over 1600 of these amplifiers have been procured from three vendors. The large, competitive procurements have driven the price down to the present \$949 each without sacrificing reliability.

The results of this program are attractive from the device standpoint but are resisted strongly by systems people. ECM systems already developed cannot use a standard tube without costly modifications. Future systems require tubes that reflect the highest capability of the tube industry and the needs for advances in the system concept. Reliability, sound hardware, and lowest cost are secondary to the system manufacturer. The system manufacturer wants to achieve three things: (1) a system that is acceptable and timely for procurement by the user, (2) a system that satisfies the performance requirements, and (3) a system that makes money. The system manufacturer will select a device that will make it possible to get the acceptable production system out the door.

The use of a standard tube poses a complex problem for the systems manufacturer. How can a standard tube be used when the proposed system is required to do more, in less space and in a more hostile environment (all within a short development cycle).

Standardization at the tube level is a long-term project, but a limited form of standardization is possible. Since the interior of many of the tubes is similar, standardization of tube subassemblies can be utilized and offers advantages in cost and reliability. Another area which standardization should address is tube connectors. Development of mature, reliable, standard rf and dc connectors for ECM systems would prevent many of the tube failures that occur because of arcing or inadequacies in these units.

Tube standardization is not economically feasible for many established systems, but for specific systems and in limited areas of tube construction it can provide increased reliability.

Standardization should be widely applied to new system developments. The next generation of ECM systems will use dual-mod. tubes. If the future developers of these systems coordinate their efforts and agree on a common tube, then a reliable, mature device can be developed for the application. The development alone will not be enough; acceptance by systems houses must be achieved.

ANALOG THERMAL MODELING

The thermal conditions internal and external to the tube are a major cause of tube failure. One useful tool for predicting thermal changes within a tube was demonstrated at

Sanders. This model — using resistors, capacitors, and current sources — is able to predict thermal changes within a tube as a function of changes in operating conditions.

The RC network represents the various junctions and sections through which the heat flows within the tube. Current sources are used to establish the initial voltage analog of the thermal distribution. The values for the current settings are related back to a thermal profile of the tube obtained from an instrumented tube. Outputs from various sections of the model are sampled by a probe and then viewed on an oscilloscope. When operating conditions change, a corresponding change is presented on the oscilloscope.

The model is a low-cost unit (\$1.5k) and can be built by a technician. Full details of the model are contained in a final Sanders report (ref 3).

This technique can be developed further and can be used to investigate thermal distribution of future traveling wave tubes, particularly where burst-mode performance is required. Alternatively, there are many thermal computer programs which would seem to offer greater flexibility and ease of input.

TESTING AND RELIABILITY

As discussed in Sanders reliability efforts, above, and Government-Industry interaction, below, the level of tube reliability that is currently available results largely from tests at the system manufacturer's plant. Sanders, ITT, and Westinghouse employ screening and burn-in tests to select the best tubes from those provided by the tube manufacturer.

This process identifies out-of-specification devices from the systems viewpoint and also identifies structural or other defects that make the tube incompatible with the system.

The process does provide a quick feedback to the tube manufacturer and thereby results in one aspect of tube quality improvement. But the improvement is systems oriented and does not provide a solution for future tube problems including in-socket life.

Screening and tube selection are effective tools for system development, but postpone the long-term solution to problems relating to tube reliability, i.e. tube design, processing, and assembly.

TEST PROGRAMS FOR IMPROVED TUBE DESIGN

Test programs such as that performed by Hughes for traveling wave tubes provide a better understanding of the safety or reliability margins.

Hughes Aircraft Company conducted a performance and life test program on 1.0-kW ECM tubes. The tubes were operated at different duty cycles under various drive and load conditions. Some tests were carried out without rf, some with the tube matched, and others with the tube looking into a high VSWR. The major type of failure was helix deterioration or complete helix failure. The lower-frequency tubes failed. The following table summarizes some of these test results:

<u>Test</u>	<u>Observed Symptom</u>	<u>Action of Protect Circuitry</u>
Vary duty cycle, no rf	Helix failure 2-3 inches from the input to the helix	Tube became gassy, had a run-away effect. The protect circuit was not fast enough
Vary VSWR and duty cycle, rf present	Helix failure, 2-3 inches from the input to the helix	

3. "Final Report of Thermal Evaluation of the QKW 1634," March 1974, Sanders (SAN-YTF-5048).

<u>Test</u>	<u>Observed Symptom</u>	<u>Action of Protect Circuitry</u>
	High temperatures occurred near the loss attenuator	
Vary duty cycle, tube matched, rf present	Plating near the output of the helix blistered. Gas produced	Gas-activated protect circuitry
Long term, short duty (pulse-burst mode)	Last 1-1/2 turns of the helix melted. This failure is typical of pulse tube inadvertently operated in cw mode	

Other problems reported included arcing at the high-voltage connector at the collector end of the tubes, and modulator malfunctions causing the grid voltage to rise excessively, ultimately destroying the grid.

The Hughes data give some insight as to what may be happening within the tubes. The failure modes are similar to the helix failures observed in the field. Better understanding of the Hughes experiment can lead to techniques for minimizing the fault conditions or specification limits that better characterize the reliable regions of operation.

GOVERNMENT-INDUSTRY INTERACTION

GOVERNMENT PARTICIPATION IN RELIABILITY OF ECM TUBES

Discussions with tube and system manufacturers revealed that the government provides very little direction to solving the early-life problem of tubes. The system manufacturer receives a contract to provide a system, determines the tube performance requirements, and lets the contract to the tube manufacturer. Tube problems are identified during the system development and the system manufacturer determines the approach to the solution.

The solutions are oriented towards making the system deliverable. Some solutions trade off tube performance or reliability for change in the transmitter, in order to get the system to work. Members of the tube industry indicated that as long as the systems house can dictate to the tube house, major improvements in tube reliability will not be forthcoming.

A major portion of the documented data was obtained from information generated by the systems manufacturer during acceptance testing of tubes or during production testing of the equipment. These data should be available to the military device development groups, but, for the most part, remain in the hands of the system manufacturer.

The tube developers also have tube information but are not free to release the data because of data release restriction clauses in their contracts.

An essential element of any Navy program to support tube reliability is access to the early tube integration problems. These data in the hands of tube houses could provide direction for developing more-reliable tubes. The feedback now is not sufficient, since the data are used only to provide a system-oriented solution. DoD could integrate such data to obtain generic solutions for tube improvement. Reliability improvement for tubes requires an independent tube evaluation capability to generate tube performance data and tube failure data, then develop programs which provide solutions at the tube level. This kind of solution will advance the technological area (not just fix the system).

NO-FAULT FAILURE

Changes in the operating modes of the government, the systems manufacturer, and the tube manufacturer are needed in order to improve reliability. Penalties and threats are associated with reports of poor tube performance. The communities using tubes should feel free to identify problem areas without fear of losing a contract or of having a program terminated. Tube problems must be identified and evaluated early in the program, and, if necessary, programs should be established to eliminate deficiencies or problems. Our present setup does not encourage the early, more-economical solution, but rather rewards hiding or postponing the more basic tube problems.

FIELD FAILURE DATA FOR THE MANUFACTURER

Every tube manufacturer complained about the lack of failure data from the field. The two major sources of information relating to product quality are obtained from acceptance testing by the equipment manufacturer and from tube faults observed during repair programs. Some manufacturers stated that the repair source of data was being eliminated because of activities at Naval Ammunition Depot Crane. For some systems, the manufacturer is allowed to look at failed tubes externally and he is not allowed to open the tubes. Crane has the responsibility to evaluate the tubes, including the tube disassembly, if necessary. Industry feels that valuable information is lost and hinders product improvement. The tube industry feels that they should have more involvement with DoD in evaluating failed tubes, and the information that Crane and others gather should be made available to the tube manufacturer.

INDUSTRY RECOMMENDATIONS FOR SMALL PROGRAMS

During the Lower Cost ECM Tube Conference held in Dayton, Ohio, in February 1975, representatives of the tube industry stated that small programs should be established to address individual aspects of a problem. Industry indicated that the small-step approach should be used to extend the present technology. By this means, problems could be identified and quick-reaction solutions provided.

Industry stated that the government should have two ongoing efforts. The first effort should provide for near to mid-term (2-5 years) programs. These should provide practical solutions to near-term requirements. The second effort should provide for long-term programs (5-10 years). These programs should be implemented through increased investments in exploratory and advanced development programs. The second, long-term programs especially are lacking.

TUBE COST FACTORS

LOW-VOLUME BUYS OF STATE-OF-THE-ART TUBES

The tube industry has identified as the primary factor in high tube cost, the separation between the state of the art and tube specification. Since most ECM tubes currently used are at the limit, the cost is high.

Two items are identified that could lead to lower tube cost: (1) greater-volume buying, leading to a lower cost position on the learning curve; and (2) greater investment in engineering development and manufacturing processes.

Industry also indicates that special items such as special test segments, software, packaging, and configuration changes contribute to increased cost.

Pushing the state of the art in tubes is costly. Given below are the estimated cost impacts of higher performance requirements.

COST FACTORS AS A FUNCTION OF TUBE PERFORMANCE DEVIATION FROM A MATURE TUBE

<u>Performance Change</u>	<u>Estimated Impact on Tube Cost</u>
Efficiency +4% to 6%	5%
Gain box from 6 (± 2) dB to 4 (± 1) dB	5%
Add grid to cw tube	35%
Dc connectors (special)	10%
multiple-pin connector (most costly)	
flying leads (least costly)	
Special	10-20%
size	
environmental specification	
burn-in	
temperature range	

COST FACTORS FOR A COUPLED CAVITY TUBE

1. Application (space, ship, etc)
2. Average power
3. Frequency
4. Peak power
5. Focusing

PPM magnetics	\$ 500
solenoid	\$3000

6. Bandwidth

7. Cooling

liquid	lowest cost
air	collector bigger
conduction	most expensive

Items 2 and 5 are critical to reliability.

COST FACTORS OF A HELIX TUBE

1. Environment

vibration
service shock
safety shock
temperature range of operation
altitude (operational)

2. Form factor

3. Match (reflected power)

4. Manufacturing yield

5. Quantity of tubes

AN EXAMPLE OF HIGH-VOLUME TUBE PRODUCTION LEARNING CURVE

In order to arrive at the maximum possible production volume impact on tube costs, an example was chosen which probably represents the highest production numbers known. The particular example is the cw magnetron used in microwave ovens. (Obviously the numbers of tubes built for military use are an order of magnitude below those built for the American kitchen.) This tube represents an upper bound on cost impact — its position is farthest out on the learning curve.

Up to 1961, the "cooker magnetron" employed an electromagnet and sold to the stove manufacturer for about \$150.00. Subsequently a tube redesign resulted in the use of an alnico speaker magnet and the price went down to \$96.00. Today the production is almost a million in the US and about 1.5 million in Japan, and the price is \$25.00. It is projected that in 1976 the price will be about \$15.00 (\$20.00 when delivered in the US). Therefore, including both the redesign and the learning curve effects, the tube impact is a factor of 10 over the 15-year period.

Table 1 gives production and cost figures, industry wide, for the years 1965 to the present (and actually shows the effects of competition as well as the production learning curve).

TABLE 1. INDUSTRY-WIDE PRODUCTION AND PRICE HISTORY,
MICROWAVE OVEN TUBE.⁴

Year	Units Produced	Unit Price (to the oven manufacturer), \$
1965	13 400	96
1966	15 400	96
1967	16 000	96
1968	28 400	85
1969	50 000	70
1970	53 000	70
1971	200 000	55
1972	350 000	47
1973	630 000	40
1974	750 000	34
1975	900 000	25 (Japanese tube delivered in US) 29 (US tube)
1976	1 200 000	20 (Japanese tube delivered in US) 15 (Japan)

MANUFACTURING TECHNOLOGY

Another approach to cost reduction in the face of low-volume buying is through manufacturing technology. As discussed earlier, the individual manufacturer does not have the economic incentive to make the investment, and DoD will have to provide the support. This can bring costs down to where they would be if large numbers of tubes were bought.

In the past, some manufacturing technology programs have been used to cover programs which were largely device development. There is a degree of overlap so that this is understandable, but at present individual tube design improvement will not provide the generic solutions which advances in manufacturing technology would provide. Basic reduction processes must be addressed: eg. production jigs and fixtures for multiple-unit operation, utilization of more castings and less machining, and more automated processes in both fabrication and testing.

As an example, a summary of a TWT manufacturing technology program is given below, giving the various stages of production and the advanced production techniques available. The example chosen is for the recirculating memory TWTs used in the AN/ALQ-126 system. (The tube numbers are M5930, M5931, and M5436.) About \$3M is spent on these tubes annually and so the potential saving is estimated to be in the neighborhood of \$1M per year. In order to achieve this magnitude of savings, a substantial investment would have to be made - almost \$0.5M.

4. This table is a composite of data gathered from an industry survey and the following sources: Association of Home Appliance Manufacturers, Arthur D Little Company, and Creative Strategies Company.

AUTOMATION OF CRITICAL PROCESSES

The automation of critical processes produces cost reduction not only from labor hours saved but, to an even greater extent, from the increase of yield resulting from tighter operational control. Two such critical operations are helix winding and pyrolytic deposition.

The slow-wave structure of the modern TWT is rarely a simple uniform helix. The demands for gain flatness, overdrive, and good VSWR necessitate pitch and diameter changes. Until recently, pitch variation (velocity tapers or velocity jumps) for efficiency, overdrive, or match purposes were wound into a helix manually. Now, by the use of a tape-controlled stepper motor, these can be wound automatically. Recently, experimental helix machines of this sort have been built which can be instructed by ASCII (American Standard Code for Information Interchange) tape to wind any sort of taper or jump required. This experimental machine has reduced the time to wind a standard helix from 30 to 2 minutes (with such low probability of error that inspection time has been similarly reduced). On experimental helices, the time savings are more spectacular; a new helix can be programmed and wound in 15 minutes where it previously took up to 2 days (new cams had to be made).

Two further areas where tape-controlled semiautomated processes should be employed are the pyrolytic deposition process and the charging of magnets. Some progress has already been made in developing an experimental tape-controlled pyrolytic deposition unit. At one TWT manufacturer, for example, a ceramic rod, constantly rotating, is pushed at varying speeds through a heater coil. The speed through the coil is controlled by a stepper motor acting on instructions from a punched tape. This, again, is an extremely critical area where human control would be taken over by machine. The greatest causes of low yield in the low-power, low-noise tubes are typically poor VSWR and gain fine structure. They are a cause of failure for which there is no remedy and result in scrapping the vacuum envelope. Both are directly dependent on well tapered attenuation.

The other candidate for tape-controlled processing is the charging and discharging of magnets. This operation is now performed by operators who (following an instruction sheet) charge each individual magnet up to saturation and discharge it to the required value. The discharge procedure is slow. The operator switches and adjusts an auto-transformer while observing the residual magnetic field strength on a fluxmeter. This is an obvious example of an operation where mechanical handling and punch tape or card-controlled processing could lead to large labor savings. Further labor savings would undoubtedly accrue from the accuracy and uniformity of the operation, improvement in tube performance and reduction in test operator time.

USE OF LASER WELDING

The advent of laser welding offers a tool with new possibilities for welding in confined spaces and making vacuum joints where high temperature creates problems. Two operations where laser welding would provide an immediate solution to problems are welding the helix to the rf input and output center conductor and attaching window assemblies to stainless steel barrels. In the former case, the weld is now made by inserting welding electrodes down into the window assembly — an extremely cramped and difficult operation resulting in a weld which is known for failures. The other problem, attaching window sleeves to a stainless steel barrel, is a matter not of space but of temperature. The temperatures required to braze the window sleeve to the barrel are sufficiently high to anneal the

barrel, causing it to lose the elasticity required to compress the helix assembly. A laser welding beam offers the possibility of making this vacuum joint without raising the component parts to high temperature.

PRODUCTION JIGS AND FIXTURES

The provision of multiple jiggling and fixturing for metal-ceramic brazes would enable guns and input and output rf windows to be brazed in large batches instead of individually as now. Batches (sufficient for a day's or even a week's production) would be fired in a cam-controlled vertical furnace, removing operator judgment from the brazing operation. The finished components would be leak-checked and stored in dry hydrogen until required for use.

The use of multiple fixturing can lead to considerable time savings wherever a vacuum system has to be pumped down. This is inevitably a slow process. Multiple fixturing can save time by enabling individual components under test to be valved in and out of the pumped system, thus requiring the whole system to be pumped down only once for a number of tests rather than for every component.

Another very similar application would be for the deposition of pyrolytic carbon on the alumina support rods. Again, the entire system has to be pumped down prior to the injection of heptane into a bell jar. Beneath the bell jar a ceramic rod is pushed through a heater coil at a controlled rate. The capacity of such a system could be increased many times by the addition of a rotating platform, supporting a number of rods, which automatically inserts the rods one by one in the coil and withdraws them after completion of the deposition cycle. Waiting time could be eliminated, since between loading the operator could be employed checking and recording the coated-rod attenuation patterns.

TESTING

Rf testing of tubes and amplifiers is an operation with a high labor content. This cost can be substantially reduced in two ways. For large-volume production, a specialized rf test bench can be constructed, which, at the operation of an rf switch, will display swept VSWR, small-signal gain, saturated power, overdrive, or noise figure on an oscilloscope equipped with interchangeable calibrated graticules. Photographs of each swept parameter can be made. The photographic method has the disadvantage of being a go, no-go system. Actual numerical measurements of each parameter can be printed out from inputs derived from power meters and the noise figure meter. Components are now available to construct an rf test system which can be instructed by punched card or tape and which will automatically test and printout the measurements. Automatic testing would be invaluable for burn-in and life test, where it could test and record a number of tubes at predetermined intervals.

POWER SUPPLIES

There is a need to study the specifications that are invoked on the supplies ordered by the government to see how they relate to automated power supply assembly and soldering techniques. It will probably be necessary to generate an acceptable series of specifications

that properly tie down the processes and inspection criteria that would ensure a reliable product through the use of the automated techniques that are currently available.

SUMMARY

	<u>Investment</u>	<u>Time, Months</u>	<u>Savings/Year</u>
Production jigs	\$25 000	6	\$360 000
Automatic processes			
pyrolytic	30 000	9	
helix	50 000	9	
exhaust	75 000	8	
magnet charge	50 000	6	
			\$200 000
Laser welding	50 000	9	75 000
Component parts	50 000	12	200 000
Testing	100 000	9	50 000
Power supplies	45 000	3	100 000
	\$455 000		\$985 000
*Pilot production run		3	

TUBE RECYCLING

Tube recycling has been used on the more costly tubes, but is not applied universally. NAD, Crane, Indiana, has been active in tube repair in recent years. It is felt by many in the field that Crane served a useful purpose in stimulating a reluctant world. At this time, however, it might be more appropriate to nurture the shrinking group of survivors in the microwave tube industry by having industry handle the bulk of tube repair. This would serve the additional purpose of providing tube manufacturers the failure-mode data for redesign of old tubes as well as new-tube development. Needed are a comprehensive survey and an evaluation of tube repairability in order to:

1. Generate a list of cost-effective candidate tubes. Elements which must be considered include repairability, repair cost vs replacement cost, availability of facilities, present and future socket population, present tube life, and the potential for redesign for super-long-life tubes.
2. Establish the logistic chain to retrieve the tube rejected from the system, repair it, and return it to the supply system (eg, SPCC Mechanicsberg). It might be desirable, for example, to require the return of the carcass for the issuance of a replacement tube -- for tubes above \$400 in cost.
3. Apply failure modes and statistics to tube redesign and future tube development.

*It is desirable for the final outcome of the program to be a pilot production run demonstrating the reduced production costs achieved and providing a measure of enhanced product performance.

Until recently, the \$10k, \$20k, or \$30k tube has been undergoing repair. The feeling was that the cost of the logistics would outweigh the cost savings for less-expensive tubes. A lesson can be learned from commercial airlines such as Pan Am and TWA. These airlines find it profitable to recycle a weather radar coax magnetron which costs \$450 new.

The benefits which are derived from tube recycling can be summarized as follows:

1. Recycling of materials.
2. Cost savings – rebuilt tube costs 60% or less what new tube costs.
3. Improved life from rebuilt tube because of improved structure resulting from examination of defects.
4. In some cases, a complete redesign is called for, resulting in a large increase in life and reliability.
5. An increased awareness on the part of manufacturers and users of the programs necessary to ensure long life for tubes in the field.

At this time, magnetrons seem to be the most repairable transmitter tube. Several magnetrons are now being repaired by contractors and one such program is described as an illustrative example.

Returned tubes are first hot tested and then cold tested to confirm the reason for rejection. If no obvious defect is found, the customer is contacted, but 99% of the time the tube is in fact defective.

After stripping off all the external hardware and grit-blasting the vacuum envelope to remove all paint, soft solder, etc. the tube is opened. This may be by machining off a welding flange, heating a brazed joint, cutting a glass insulator, or various combinations. All portions of the tube are then examined for defects. Defects that are usually found include:

- Heater problems
- Emitter and end-hat defects
- Emitter support structure distortion
- Anode distortion
- Tuner distortion
- Evaporation or arcing deposits

All sections are then cleaned either by mechanical abrasion or by hydrogen furnacing (but without using acids or fluids).

Necessary parts or subassemblies are provided and the tubes are then reassembled in stages with dimensional, temperature, and cold test checks being made at each step. Glass parts are resealed on a glass lathe and leak-checked on a helium mass spectrometer.

Tubes are then baked out at a temperature in accordance with the original design (based on the presence of glass or silver). On initial test, an attached ion pump is used to monitor pressure and also absorb any gas evolved at this stage. After adequate aging, this appendage pump is pinched off. The tube now has its original external hardware attached and is tested and shipped.

In general, tube yield is higher than 80% and tubes can be rebuilt a number of times.

Because each tube is individually tested and then structurally analyzed, the failure modes soon show up in the statistics. Most of these original failure modes can be eliminated

entirely by changing the design of a portion of the tube. This design change is usually a change in physical configuration related, not to electrical performance, but to mechanical stability over repeated thermal cycling.

Most of the original parts are used again with significant savings in machining operations and raw materials.

Examples:

RM. 101: 25-kW CW Magnetron, L-Band (\$4000 new-tube cost)

The directly heated cathode burns out and is replaced. Original design had a braze near the hot cathode which fatigued. It was replaced by a weld with improved life. These tubes are rebuilt many times. Stage 1 replaces cathode only, but eventually the welding flanges have to be replaced, which is stage 2. The design of new tubes now incorporates longer welding flanges to facilitate repair.

RM. 103: 75-kW Pulsed Coaxial Magnetron, X-Band (\$450 new-tube cost)

This tube is used in commercial weather radars and has an initial life of many thousands of hours. The main faults showing up are distorted anodes and distorted or broken cathode supports. Anodes are mechanically straightened with a specially designed tool and then stress relieved. All cathode assemblies are replaced with a more rugged structure.

RM. 114: 2-MW Pulsed Magnetron, S-Band, Narrow-Band Tuner (\$2500 new-tube cost)

These tubes have two main defects:

The cathode is a nickel-based oxide type.

The tuner arcs and eventually seizes.

In this case, the cathode is replaced by a tungsten-based dispenser type with potted heater which should outlast the original by a factor of 10. The tuner is completely removed and replaced by a version with a choke, to eliminate arcing; and a welded bellows, to increase the cycled life and reduce backlash. This is necessary to take advantage of the increased cathode life.

75-kW Pulsed Magnetron, C-Band (\$725 new-tube cost)

Failure modes:

Heater burn-out, which is usually fairly early in life.

Severe power fall-off resulting from a fatigue failure of the brazed joint supporting the cathode.

The improved design uses a potted heater and a redesigned cathode support with different materials resulting in a lower operating temperature of the brazed joint.

70-kW Coaxial Magnetrons at X and Ku, Both Frequency Agile (\$6000 new-tube cost)

These magnetrons are used in the C5A radar and are particularly expensive because of the frequency-agile feature.

In this case, there are two separate considerations: the vacuum section and the frequency-agile drive mechanism which is external to the vacuum envelope.

The former has two failure modes associated with the cathode and its support structure:

- Emission build-up over the structure resulting in reduced power output.

- Distortion of the structure with the same result.

The entire cathode assembly is replaced by a new design, which is treated to inhibit emission from the support, which has no brazed joints operating at high temperature and maintains its original shape.

Problems with the external portion usually involve bearing failure. At the moment, the bearings are replaced by the original type, but a redesigned lubrication system could be expected to result in an improved life.

Most of the work has been performed on commercial tubes which have been readily obtainable. The C5A tubes were made available by the main maintenance base located at Kelly Air Force Base at San Antonio, Texas.

RELIABILITY FOR FUTURE AIRBORNE AND SHIPBOARD SYSTEMS

Reliability is incompatible with new-tube format or types for new ECM applications. Tubes that demonstrate full performance and reliability are usually old tubes (in a development sense) that have been used in systems with essentially the same requirements for a long time. In order to achieve reliability of a new tube in a new system, the tubes should be developed in advance so as to anticipate system requirements.

AIRBORNE SYSTEMS

Currently there is a need for dual-mode tubes so that cw and pulse capability can be obtained in the smallest package and at the lowest weight. To achieve this, full-specification dual-mode tubes must be developed now to satisfy projected system needs. Not only dual-mode tubes need to be addressed, but the power supply modulator for operating these tubes in a reliable manner must also be developed (an integrated total transmitter package development).

If advanced development is pursued for dual-mode I/J-band tubes and transmitter, and the effort is coordinated with the Air Force, a low-cost, reliable unit will be available for the next generation of ECM systems. The advanced development should cause the units to be achieved at low cost and to demonstrate good reliability early in the system life cycle.

SHIPBOARD SYSTEMS

Shipboard systems require high power over an octave bandwidth for self-protection. Currently, high-power systems at the multikilowatt level are available at fractional-octave bandwidths. With current technology, octave-bandwidth tubes are not possible at the high kilowatt levels required. An alternate approach is therefore necessary.

High peak power over an octave bandwidth can be achieved by paralleling mature, reliable tubes of lower power and octave bandwidth. Since I/J-band tubes are being developed for airborne applications, these same tubes should be considered for shipboard applications.

The airborne tubes are used in quantity and are maturing rapidly. Use of these devices will permit timely development of a high-power, paralleled amplifier for shipboard implementation.

The power supply for this application must not be neglected. The reliability of the parallel-tube approach is directly a function of the marriage between the power supply, modulator, and tube.

At present, the Naval Electronics Engineering Office (NEEO) at Norfolk, Virginia, is engaged in paralleling studies to achieve higher power. (Their activities should be coordinated with the developments of the airborne I/J-band tubes so that maximum return can be realized from the two efforts.)

STATUS SUMMARY OF SYSTEMS SURVEYED

The following summary represents the results of the survey made of ECM/radar systems. Wherever possible, the problems were delineated and solutions were recommended. Available population statistics and projected bugs were included. The systems included do not make up a comprehensive list but rather represent those systems with identifiable problem areas.

In addition to the systems survey, a group of generic problems was noted and programs addressing these problems are given.

SHIPBOARD ECM SYSTEMS

	<u>Status</u>	<u>Comments & Recommendations</u>
System 1	<p>Approximately 100 high-power amplifiers are currently operational which use Hughes 338H or Litton L5335 traveling wave tubes.</p> <p>Present tubes run 500 hours MTBF, but it has been demonstrated that this can be extended to over 4000 hours. Qualification program for improved tubes anticipated and development of new setup procedures; system modifications involving improved built-in tests are being considered.</p>	<p>Many failures attributed to inadequate technician training. Setup procedures need to be simplified and installers trained in new techniques. Recommend industry-conducted training seminars after system modifications and field testing are completed. (Improved output componentry required.)</p>
System 2	<p>Incorporates either Raytheon QKW 1132 or ITT F2085. ITT tube incorporates beamscraper.</p>	<p>Dominant failure modes are open helix and failure to hi-pot. Improved potting materials and encapsulation techniques recommended.</p>

StatusComments & RecommendationsSHIPBOARD ECM SYSTEMS (Continued)

System 3 System is currently being prepared for OPEVAL. Utilizes improved version of PPM coupled cavity TWT now deployed in AM4530 HPAs plus a new PPM coupled cavity TWT in a higher band. Full-bandwidth tubes currently in advanced development.

System will benefit from experience of qualifying low-band tubes in current fleet-deployed HPAs. Improved high-band tubes will be available in December 1975. Implementation of simplified setup procedures leased in AN/SLQ-19 should make reliable tubes possible.

AIRBORNE ECM SYSTEMS

System 1 System MTBF approximately 200 hours with band 7 tube averaging 460 hours life (70 removals to date). High percentage of power transmitted at spurious frequencies. Population: (end 1974)

Very poor high-altitude performance. Redesign or new design for single tube to be used for bands 5/6/7 being considered. Other problems include:

Seepage of Coolanol/contamination

Solenoid protect circuitry inadequate

Potting problems

	B-4	B-5/6	B-7	B-8	B-9	Total
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Transmitters	76	68	170	87	127	528
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Spare TWTs	120	61	326	63	104	674
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Total output TWTs	196	129	496	150	231	1202
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Poor-quality 6-pin dc connector

Attenuation has been destroyed by reflected power

Tube is unable to operate into short circuit

Coaxial connector limits power capability and is not mode free

Lead problems caused by mishandling of cable connected to tube

Protect circuit inadequate and improper sensor location

Standby mode does not provide for reduced filament voltage

Reflective harmonic filter

Improper location of sensors

Review and analyze the position of high-power rf components in the transmitter to assure that they are optimally located. Recommend changes where necessary

Recommendations are as follow:

Develop improved potting materials and techniques

Develop TWTs that can survive operation into a short circuit for a specified amount of time

Improve the high-altitude performance of the 6-pin dc connector

Improve the coaxial connector or develop a broadband waveguide output

Evaluate and modify protection circuitry for the tube and power supply

StatusComments & RecommendationsAIRBORNE ECM SYSTEMS (Continued)

System 2

Incorporates STQ 54002 and
VTR 6224A1

Failure mechanisms are tabulated below:

Tube Type	Failure Mechanism	% Systems Accept- ance Test Failures	% Field Return Failures
		Number of faults observed	
STQ54002 High-Band Tube	Mechanical damage	27.0	29
	Osc CWOR pulse	18.0	1
	High helix I	12.5	5
	Excessive bias	10.0	3
	Collector bd	7.5	47
	Power to air	7.5	1
	Low power or gain	4.0	8
	Retest good	12.5	6
VTR 6224A1	Incorrect label voltage	6	
	Power focus and output VSWR	4	
	Low gain		1
	Mechanical damage		1

System 3

Problems with low-band tubes have been resolved. High-band tubes presently being supplied by Hughes, Varian, and Raytheon (Litton has also developed a tube). Each source has specific problems as identified by Sanders Assoc (systems manufacturer). Although the PRIDE tube does not present an obvious reliability problem due to tight screening, yield is low because of the screening, causing high per-unit cost (about \$7k).

A total of 900 systems is projected of which 600 have already been delivered. 260 will be bought in FY76.

Major deficiency is low power output (0.5 to 1.0 dB) at high-band edge. Attributable to poor beam optics and inadequate production controls.

Recommend short-term improvement programs with the tube manufacturers. Improved tubes should be available for follow-on system production and spares. Objectives for each improvement program will be formulated jointly by NAVELEX/SANDERS.

Status

Comments & Recommendations

SHIPBOARD RADAR SYSTEMS

System 1

Under AEGIS and ELEX 304 a baseline of feasibility models of high-power tubes has been developed and successfully implemented through to the system EDM stage. An opportunity exists to refine these tube types before the production phase of the development cycle.

Over 150 high-power amplifier driver and switch tubes are employed in each transmitter. A 30% improvement in tube life can effect savings of over \$0.5M/year per system.

Recommendations are as follows:

Refine design and fabrication techniques for the 125-kW crossed-field amplifier employed as the final amplifier in the radar with the objective of reducing the tube unit cost and doubling the tube life.

Conduct a design refinement and life improvement of the 10-kW driver TWT. Tube life is currently running between 500 and 2000 hours. This effort will cover a redesign of the cathode and gun structure plus life and environment evaluation to meet the life objective of 10 000 hours.

Develop a long-life tetrode switch tube to replace the EIMAC Y633 tube used in the radar. The required MTBF for the tube is 20 000 hours. The actual tube life in the system is running between 500 and 2000 hours.

Conduct a design refinement of the I-band VT 6610 traveling wave tube used as the final amplifier in the Mark 74 CW Illuminator in the Mark 99 Fire Control System in AEGIS. The required system MTBF for the tube is about 5000 hours. The present tube life varies between 100 and 2000 hours. This program is aimed at reaching a minimum tube life of 5000 hours. There are a lot of tube-system interface problems that must be solved.

System 2

Present population of these radars is over 400 units employing type 6344A/QKH 253 magnetrons. The tubes exhibit MTBF of 400 to 500 hours, imposing a high maintenance burden in replacement and system readjustment costs (exceeding \$1.0M/year).

Two programs have been initiated to replace this system: an all solid-state version (with the exception of the magnetron) and a NELC/NAFI development under the NELC Modular Radar Program. Both new systems will employ the SFD-341 or SFD-373 coaxial magnetron with 15 000 hours MTBF.

The recommended modification will effect a savings of \$1.0M/year between now and the time when the new systems are to be installed aboard ship.

Modify existing systems by replacing the existing magnetron with the more-reliable coaxial types. Install a new circulator/duplexer to improve rf loading characteristics. Modify circuitry to permit 100-nanosecond pulsed operation for 25-yard minimum range. The proposed effort will be for Varian to provide a documented modification kit to the Navy which will be installed under supervision at a depot maintenance facility, field tested, and monitored for R&M improvement.

The approach recommended can be made at low cost (\$10k-\$12k per system), and will provide the fleet with the required short-range capability as well as a sustained yearly operational cost savings during the interim period before the newer systems are completely installed.

Once the radar is modified, the tube should not need to be replaced until the set is scheduled to be replaced by the solid-state AN/SPS-10 or the Class A Modular Radar. Any tubes left in the supply chain would be spares for the new radars. After the development and qualification of the kit, all procurement costs would be simply parts replacement costs (available from existing funds for the current 6344 magnetron).

Status

Comments & Recommendations

AIRBORNE RADAR SYSTEMS

System 1

The gridded traveling wave tube in the AN/AWG-9 radar has been in continuous production at Hughes Torrance since before 1968. The tube has undergone three major design changes in the radar, and many production efficiency techniques have been applied to reduce cost; eg. fine edge blanking of the circuit parts to reduce a cavity part cost from \$5.00 to \$0.75. Many early reliability problems associated with the tube/modulator interface have also been met and solutions implemented.

The latest information from the field (CVAN 65) indicates that the tube removal rate is around 225 mean flight hours between maintenance actions (MFHBMA) and the transmitter module is about 27 hours MFHBMA. The GWT "on time" is 1.6-1.8 times the flight hours, or about 400 hours. Miramar data indicate about 500-hour life on the tube. Historically, two-thirds of all tube removals are repairable.

The AN/AWG-9 off-line R&M improvement program has identified specific modifications to be designed, evaluated, and documented for future ECP action. Within the scope of the present \$2 400 000 effort, no attempt will be made to improve the gridded TWT.

A proposed effort will be to provide improved-design GTWTs with improved performance margins. This will have a major impact on the failure rate as well as effect a minor cost improvement. This effort will be integrated with the off-line R&M program. In addition, a second-source development is recommended to provide a strong incentive for keeping the price down. Projected production numbers and price make it possible to support two sources. However, no other tube house has the present capability to produce what still remains a state-of-the-art device. PMA 241 has funded a second-source development, but they are not yet capable of competing. Additional support will be required.

The peacetime flight hours for the F14 should be 30 hours per month. This translates to about 600 filament hours/tube/socket/year. At the present failure rate, this means more than 400 tubes/year will have to be replaced when the full complement of 360 sockets is achieved. However, the present Beyond Economical Repair rate of 35% means that only 140 replacement tubes will be required at a cost of ~\$30k (FY75 dollars). The remaining 260 replacement tubes can be acquired through tube repairs at an average cost of \$4000 each. The total annual cost for 400 replacement of tubes would, therefore, amount to ~\$5 200 000. A doubling of the useful in-socket life would represent an annual savings of \$2 600 000.

The present tube production rate is 20/month at \$27k per tube. Doubling the life of the tubes would recover the investment of \$1 000 000 in 1 year.

Based on a detailed analysis of the Kennedy Aircraft Carrier which reported a TWT MFHBMA of 285 hours, the actual primary MTBF of the tube was 1800 hours. In general, at least 60% of all tube removals are either not confirmed or secondary in nature. That is, the failure was induced. Therefore, any real significant improvement in tube life will come about primarily by a transmitter/interface improvement program which the R&M program addresses.

FIRE CONTROL SYSTEMS

System 1

NSWSES has reported that a cause of 8-406 klystron unreliability has been essentially the solenoid-mechanical interface, lack of adequate vibration techniques, and substandard performance.

Beam wavering caused by poor focusing is limiting the output

Performance is limited in power and bandwidth. In addition, solenoid incompatibility problems exist. The following tasks are therefore recommended:

Perform computer analysis of existing rf structure and modify tuning cavities to effect improvement in power and bandwidth performance.

Develop better controls for solenoid parameters to assure performance with regard to mechanical interface and magnitude of transverse fields.

Status

Comments & Recommendations

FIRE CONTROL SYSTEMS(Continued)

System 1 (Continued)

power. The structural mechanics of the coil are such that the coil can be deformed. This deformation leads to poor beam control, causing subspecification performance or tube failure. The mechanical fit of tube in the solenoid also impairs beam focus and causes similar problems.

The tube should be modified to incorporate an isolated collector. This would allow better monitoring of klystron body current, providing better sensor access and a means to protect the klystron.

Present: average operating time, 150-300 hours; cost, \$7630.

Goal: average operating time, 5000 hours; reduce cost to \$4000.

A larger Vac-Ion pump would provide for a quick pump-down of the tube after an ion burst or sudden outgassing of the tube. This could also improve cathode life by minimizing poisoning by gases.

This will result in an increase in tube yield by fewer subspecification tubes being produced, and prolong tube life by providing better control of electron beam parameters. In addition, better system performance will be realized by decreasing dependency of system parameters (range, etc) upon selection of operating frequency.

VA 828 Used in three different systems

The VA 828 klystron is currently bought to three specifications: Raytheon, Sperry, and a MK 68 specification. Variation of specifications is primarily in the testing areas. Reported operating life for this tube is between 3500 and 4500 hours in System 1 and between 1400 and 2700 hours in System 2. Operating lifetimes of 10 000 hours should be possible through a tube improvement program. Tuner life reliability is low.

Identify cause of differences in observed tube life. Generate single specification for a standard tube to satisfy the three system requirements. Develop a permanent magnet for the klystron.

Tube life can be increased by a factor of 2 for the AN/SPG-55 and by a factor of 4 for the AN/SPG-51. The tube and magnet technology developed will be applicable for other tubes used in guidance/illumination functions. Reduction in weight by employing PPM focusing will effectively decrease the failures presently caused by mishandling.

Present life 4000 hours - SPG-55
 1400 hours - SPG-51
 cost \$1670

Goal life 10 000 hours, effective cost \$1000

System 2

Three versions of the klystron now exist. It is desired that the three tubes be replaced by one tube and that the magnetic

It is recommended that the VA 825 design be modified to incorporate these changes: Replace oxide cathode with impregnated tungsten cathode.

	<u>Status</u>	<u>Comments & Recommendations</u>
<u>FIRE CONTROL SYSTEMS (Continued)</u>		
System 2 (Continued)	<p>structure be changed from solenoid to PPM focusing.</p> <p>There are 100 systems in the inventory (one tube per system).</p>	<p>Modify rf circuit to include new tuner. This will provide for increased efficiency and bandwidth.</p> <p>Employ permanent magnetic focusing.</p> <p>Improve collector design.</p> <p>This program will provide an overall reliability improvement and increase life from 2500 to more than 10 000 hours. Cathode life is expected to be greater than 25 000 hours. The output power and efficiency will increase by 25%. Tuner life could also be enhanced. As a result of the focusing change, the tube would have less weight and would be less subject to mishandling. Implementation of the total program should increase life by a factor greater than 4.</p> <p>Present life: 2500 hours; cost, \$1850</p> <p>Goal life: 10 000 hours; effective cost, \$1000</p> <p>Cost savings: total annual savings is \$200 000.</p>

RECOMMENDED TECHNOLOGICAL DEVELOPMENT PROGRAMS IN SUPPORT OF HIGH-POWER TUBES

MULTIPIN HIGH-VOLTAGE, HIGH-ALTITUDE DC CONNECTORS

Equipment: All ECM equipment

Performance limitations:

Existing TWTs employ connectors that do not perform properly when ECM systems are airborne. Tube manufacturers and fleet personnel have complained that some connectors are at altitudes above 30 000 feet.

Desired performance:

Connectors should be capable of good performance at 50 000 feet.

Connectors should be arc-free and corona-free when used at high altitudes and with appropriate TWT voltages, 15 kV or more.

Pay-off if the desired improvements are achieved:

Maintain system capability if the system is employed above normal altitudes.

Reduce the number of tube replacements caused by connector failures.

Comment: NAD Crane is currently addressing the problem. Crane effort should be coordinated with another program to develop a standard high-voltage, high-altitude connector for the Air Force and the Navy.

Estimate of cost and time:

Cost \$75 000

Time 12 months

INTERNAL ATTENUATOR DESIGN TO IMPROVE MISMATCH STABILITY AND REFLECTED POWER HANDLING

Equipment: All ECM equipment

Performance limitation(s):

Existing PPM focused TWTs are not capable of operating into a short circuit from a stability or reflected-power point of view.

Desired performance goals:

Short-circuit stability of PPM focused TWTs.

An interval attenuator design capable of dissipating the reflected power from a short/open circuit for a finite length of time.

Pay-off if the desired improvements are achieved:

Survival of the TWT in the event a component in the rf output failed.

High mismatches during system operation would not cause loss of the TWT and hence loss of system capability.

Operator error during installation and checkout would not cause loss of the TWT.

Estimate of cost and time:

Cost \$50 000

Time 12 months

HIGH-POWER RF CONNECTORS AND COAX TO DOUBLE-RIDGE WAVEGUIDE TRANSITIONS

Equipment: High-power, high-frequency ECM

Performance limitation(s):

As the frequency and power available from TWTs increase, the output transmission line is unable to transmit the power from the TWT to the antenna. This is particularly true in coaxial transmission lines and coax to double-ridge waveguide transitions. At the present time TWTs are capable of greater average power than the associated rf systems.

Desired performance goals:

To raise the power handling capabilities of rf connectors and coax to double-ridge waveguide transitions to a level such that they have greater power handling capabilities than those presently available from TWTs.

Pay-off if the desired improvements are achieved:

Better overall system reliability by improved TWT rf output system interface.

Better utilization of the present state-of-the-art power handling capabilities of TWTs.

Estimate of cost and time:

Cost \$100,000

Time 12 months

POTTING MATERIALS AND ENCAPSULATION TECHNIQUES

Equipment: All ECM systems

Performance limitation(s):

Existing potting materials are unstable at the high temperatures encountered in TWTs. These materials do not bond well to the insulation covering wires or to the surface of metals. This bonding failure has caused arcing and has caused tubes to be unacceptable for system operation.

Desired performance goals

Develop potting materials capable of operation at 300°C.

Develop potting materials or techniques that will eliminate the voids during encapsulation.

Pay-off if the desired improvements are achieved:

Reduce arcing in TWTs.

Reduce the number of tubes removed because of arcing when the true cause is faulty potting techniques.

Improve the reliability of TWTs by increasing the potential life of the encapsulant. The stability or life of encapsulants is proportional to temperature. Increase in temperature capability will provide a greater usable life.

Estimate of cost and time:

Cost \$60,000

Time 6 months

SUMMARY OF RECOMMENDED TUBE/SYSTEM EFFORTS

After reviewing the status of systems surveyed, a number of efforts are recommended. The population statistics and cost and performance impact are given wherever possible.

	Proposed Effort	MTBF kilohours		Projected Savings/Yr
		Before	After	
Shipboard radar system 1	Varian 261 (CFA)	\$8-\$12	---	\$400k/system
	Develop 2nd source; double life; improve performance	5-8	10	
	Driver TWT	\$12	\$8	\$20k/system
	Improve performance, life, and fabrication and test methods; need 2nd source	2	10	
Airborne radar system 1	CW Illum TWT	\$30	\$15	\$800k/yr
	Cost reduction program benefits			(MK 99 application)
	MK99 FC systems (50)			
	Mod tetrode improve heater, cathode structure	\$50-3500	\$5-10	\$60k/system
Shipboard radar system 2	Redesign tube for reliability at high duty cycle; improve grid modulator and solenoid. Establish 2nd source.	\$30	\$20	\$3k/system
		500	1000+	
	Replace 6344 W/SFD341 coax, mag	\$760	\$3500	\$1M/yr
	Modify pulsewidth to 0.1 μ s.	500	4000	
PHALANX PMS 404-30	Redesign WG output section			
	Manufac technology program (klystron); improve tooling design, tuner, reduce wgt. Alnico or rare earth suggested.	\$30	\$20	\$10k/system
		---	---	
	Manufac technology program (klystron); improve tooling design; 20# wgt reduction, motor improvement; additional channels	\$8	\$3	\$5k/tube
SHRIKE PMA 242				
	VA828 (klystron)	\$1850	\$1000	\$650k/yr
	Standardize spec (3 used now).	3.5-4.5	10	(sustained)
	Improve tuner life and focus (also for SPG-51 application)			
Fire control system 1				

	Proposed Effort	MTBF kilohours		Projected Savings/Yr
		Before	After	
Fire control system 2	8406 (klystron); improve focus; increase bandwidth; increase ion pump cap; isolate collector	\$7630 150-300	\$4000 5	\$1-1.5M/yr
	7156 (MAG); replace w/coaxial mag	\$400	\$4000	\$250k/yr
	STC-278 (TWT); est continued supply (manu out of business)	-	-	NA
	STC-279 (TWT); est continued supply (manu out of business)	-	-	NA
	SS replacements for STC-278 CW TWT	Under consideration		-
	VA825 (klystron); improve tuner life; standardize-improve focus	\$1670 2700	\$1000 10	-
	VA828 (klystron); Same as AN/SPG-55 above	\$1850	\$1000	-
	SQU293 (klystron); establish continued supply (manu out of business)	-	-	NA
	SRC64D (klystron) establish continued supply (manu out of business)	-	-	NA
	SAC 45, 46, 47 (klystron) establish supply (manu out of business)	-	-	NA
IPD/TAS	SAC 42 (klystron); establish continued supply (manu out of business)	\$7-12	-	NA
	7390 (thyatron); improve tube or develop solid-state replacement	150-700	\$3000	
	QKW1701 (TWT); increase yield-now 20%; refine design -200 to 300 kW power handling capability	\$25 4000	\$13 8000	\$15k/system
	TWT; develop domestic tech; establish US source; reduce cost	\$85	\$45 3000	\$1.2M sustained
SURVSATCOM	Improve tube (mag) and tuner life	\$3-4	\$2	\$1k/system
	Refine tube (TWT) performance (variation of output overband) heater-cathode problem	\$11-16		-
HARPOON				
AN/APS-116				
HIGH-POWER SHIPBOARD ECM				
	Develop improved tube (TWT); set up procedures, tube protection methods	\$18-20 1	\$18-20 4	\$12k/system